PHASE EQUILIBRIA CONSTRAINTS ON ARCHEAN CRUSTAL GENESIS FROM CRYSTALLIZATION EXPERIMENTS ON TRONDHJEMITE WITH WATER AT 10-17 KBAR;
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The formation of continental crust during the Archean and early Proterozoic occurred through a different mechanisms than the currently active processes of calc-alkaline volcanism in orogenic regions. In view that most crustal growth models imply that by the end of the Archean a continental mass equivalent to 75% or more of the current crust had evolved, it seems highly relevant to study early crustal genesis.

Grey gneisses of tonalitic- trondhjemitic- granodioritic- (TTG) composition form the dominant rock type of Archean basements. Their proposed origin from a protolith of hydrous basaltic composition through single stage melting, or, involving remelting of TTG's in a multi stage process, seems to satisfy trace-element and isotope constraints (Jahn et al., 1984). Rigorous testing of phase equilibria of such models has been largely ignored. Our here presented results on Nûk Gneiss (Greenland) form part of a nearly completed comprehensive study of the phase equilibria for tonalites of diverse composition at lower crustal pressures. The composition subject of this study is given in the table in column 1.

Experiments were carried out with powdered natural starting materials sealed with water in gold capsules and run in a piston and cylinder apparatus using NaCl assemblies. Run durations ranged from 48 hrs at 1000^{0}C to 200 hrs at 650^{0}C. The phase diagram for trondhjemite water at 10 kbar (Fig 1A) is based on 38 experiments and compared to the results at 15 kbar (Fig 1B) of Johnston and Wyllie (1988) for the same composition. At 10 kbar liquidus phases are with increasing water: plagioclase (Pl) at >1000^{0}C with <3.5wt% water, clinopyroxene (Cpx) at 850-1000^{0}C with 3.5-7wt% water, and hornblende (Hb) at 800-850^{0}C with >7wt% water. At 15 kbar liquidus phases are: Pl at >930^{0}C with <5.5wt% water, garnet (Ga) at 890-930^{0}C with 5.5-8wt% water, Hb at 890-780^{0}C with 8-13wt% water and epidote (Ep) at 740-780^{0}C with >13wt% water. The order of appearance of hydrous phases with decreasing temperature at 10 kbar is Hb, biotite (Bi), Ep but reverses at 15 kbar to Ep, Bi, Hb. Above 800^{0}C the anhydrous mafic phases are Cpx and orthopyroxene (Opx) but these are replaced by Ga at 15 kbar. Subsolidus assemblages are identical at 10 and 15 kbar and consist of Pl+Qz(quartz)+Bi+Ep. Muscovite, present in addition to the subsolidus assemblage in the starting material, is absent in the run products. Using additional results at 12.5, 13 and 17 kbar the inferred stabilities of mineral phases on the water undersaturated liquidus are indicated over a large range of pressures and temperatures.

It is generally accepted that Hb and or Ga cause the strongly fractionated REE patterns with low HREE in Archean rocks of the TTG series. Our near-liquidus phase equilibria imply that this composition is in equilibrium with Hb+Ga+Cpx+Pl at about 900^{0}C, 14 kbar and 7-8wt% water and could be derived from a basaltic source under these conditions. With lower water contents Pl fractionation is likely to occur but this would conflict with the normally absent or positive Eu anomalies in trondhjemites. Further steepening of REE patterns in secondary melts generated from this composition could occur at 10 kbar with 6wt% water at temperatures as low as 700^0. Under these conditions 50% partial melts in equilibrium with Hb+Opx+Pl+Qz still have a trondhjemitic composition (Table, column 2). At 10 kbar and 650^{0}C with 6.7wt% water, however, K_2O contents markedly increase and melts now in equilibrium with Ep+Bi+Pl+Qz are more of a granitic composition with Na_2O/K_2O around 1 (Table, column 3).

Jahn, B.M., P. Vidal, and A. Kröner (1984) Contr. Mineral. Petrol. 86:398-408.
Johnston, A.D., and P.J. Wyllie (1988) Contr. Mineral. Petrol. 100:35-46.

ARCHEAN TRONDHJEMITE: van der Laan, S.R. et al.

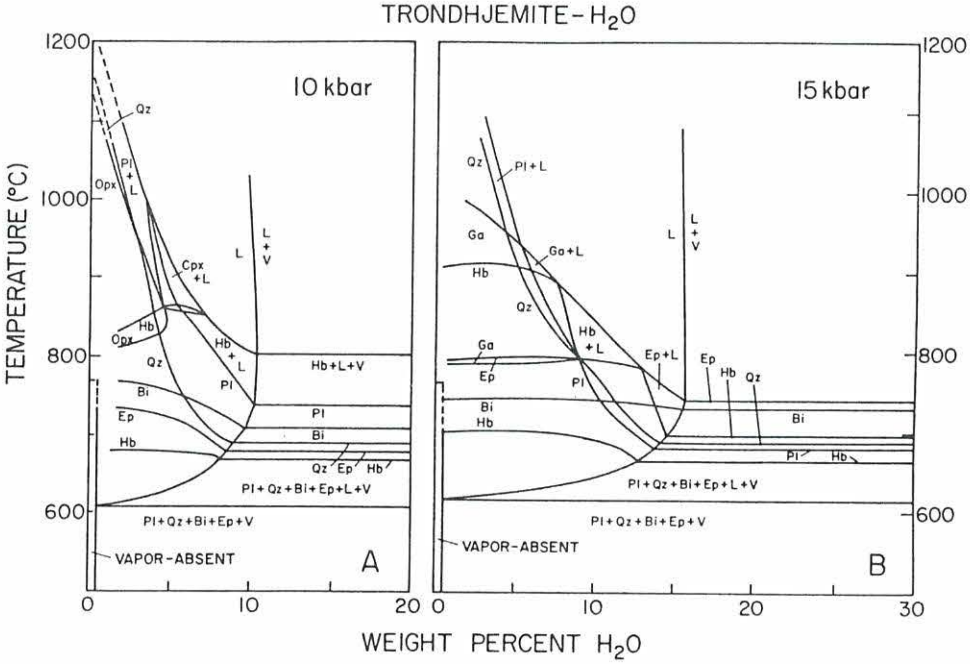

Fig 1.: The effect of water on the phase relations for Nûk Gneiss at 10 and 15 kbar. Each phase field boundary is marked by the changing phase on its stable side of the boundary only. The results at 15 kbar are after Johnston and Wyllie (1988). For abbreviations see text.

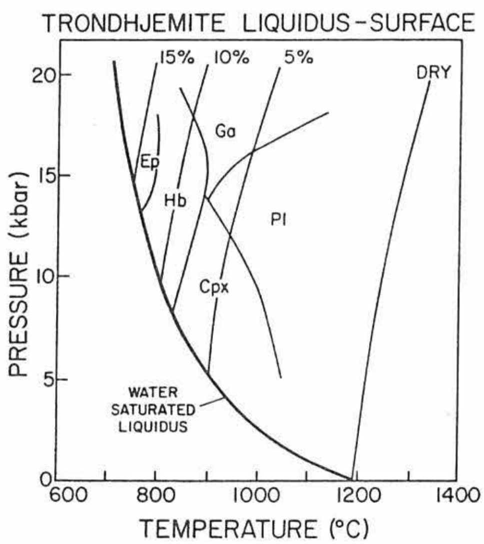

Fig 2.: Water undersaturated liquidus surface for Nûk Gneiss with outlined stability fields for liquidus phases. The surface is contoured for water content. At 900^{0}C, 14 kbar and 7-8wt% water this composition is in equilibrium with Hb+Ga+Pl+Cpx. For abbreviations see text.

Table: Melt compositions in the experiments.

	Starting Composition	700^{0}C, 10kbar 6wt% water	650^{0}C, 10kbar 6.7wt% water
SiO_2	71.1	75.1	71.5
TiO_2	0.2	<0.1	<0.1
Al_2O_3	16.5	15.0	16.2
FeO	1.3	0.9	0.9
MgO	0.6	<0.1	<0.1
CaO	2.8	2.2	3.5
Na_2O	4.9	4.3	3.5
K_2O	2.3	2.4	3.6
total	99.7	100.0	99.5
assemblage		+Pl+Qz+Hb+Bi	+Pl+Qz+Ep+Bi

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